Flight Operations in the New Millennium

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ABSTRACT—New approaches are being studied for real-time interaction and related supporting processes with spacecraft and instruments in deep space. Spacecraft are evolving, improving in many ways, and generally becoming more robust. Operations is changing also. Operations will be more automated in the future. However, there is a challenge. Deep space missions are not all alike. The Operations phases of discovery and exploration are an extension of the research that creates the mission; they are the time of obtaining results.

This document examines the historical role of Flight Operations, and its evolving processes, to develop an understanding of the operational methods that will be effective in the future.

It takes people, equipment, software, space and connectivity for Operations success. A balance has to be struck between improving technology, gaining knowledge, and automation, and what expectations are realistic.

Finally, the recommended methods to gain efficiency in Operations are system-wide services and shared resources. These common processes will meet the challenge of varied missions.

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1. INTRODUCTION

Space exploration is going through a cycle of rapid evolution. There are a number of reasons, but possibly the most significant has to do with costs. At a time when the desire for exploration is increasing, the cost factors are becoming ever more restrictive. The very history of National Aeronautics and Space Administration (NASA) space exploration explains why innovation and technology improvements are proliferating at the present time. Even though spacecraft were tested in an end-to-end mode on the ground prior to launch, there were always surprises during flight. Operations personnel learned to patch and correct, finding effective ways to accomplish a task. The complaints about high overall mission costs usually point to operations as being porportionally too expensive a phase. One could argue that in the past, this was justified. Operations was truly at the cutting edge, and it took a lot of people and equipment to accomplish a mission. At that time, we in Operations always pressed on, looking for other opportunities, as long as the spacecraft and the money held out. The situation is changing. The goals are the same, but we have to work smarter.

We must become more efficient in Operations. The challenge is there. By applying new Operations concepts and by using advanced technology, both on the ground and in space, we can provide the means for continued scientific exploration.

2. THE CHANGING ROLE OF OPERATIONS

Spacecraft systems, both hardware and software, are going through a transformation of their own. The technology advancements and the cost limitations mentioned above are causes in themselves, forcing Ground Operations to innovate and evolve along with the flight system While this document is directed at Ground Operations, it is important not to separate Ground Operations from Flight System Operations. They need to be looked at as a complete, end-to-end system. As spacecraft become more automated and more fault tolerant, the Ground Operations portion, most especially the uplink process, has to adapt to the flight system. So the two operating systems must be considered as a complete system. Flight and ground software need to be designed, developed, tested, and operated together for success. This need for concurrent engineering is making a significant change in Operations.

Automation of the downlink data flow means that it does not take a team of people to ensure that all the available data get to the right project's computers.

The uplink process has always been the more labor-intensive, being the most critical of the two activities. Newer automatic uplink functions, with all their checks and verification capabilities, coupled with the improved ability of the on-board flight system to protect itself, have greatly simplified the process, and provided the assurance of command quality.

The push to reduce Operations costs has also caused organizational changes. The traditional dedicated specialty teams of the past are giving way to multitasking within a project; a multimission service, defined as "function sharing" across a number of projects; or the possibility of institutional Operations services.

Another option for consideration is the use of multi mission teams. Personnel arrd equipment can be shared—-spread among a small grouping of missions. The obvious advantage here is reduced cost while still having a semicustom team. The disadvantage is difficulty with any deviation from a plan. Will there be sufficient response to any circumstance? Team members might be busy with other planned tasks. The risk of this disadvantage generally remains small, and is usually outweighed by the cost advantage.

Operations services can be very useful; they can be performed efficiently and at low cost. They can be a real advantage in the downlink process: seeing that data are collected, complete, and routed to project computers. In a limited manner, they can handle simple uplink operations. Generally they are spread over a broad spectrum of missions, and do not have individual missions' details. They can provide the alert in case of alarms or any deviation from a plan. They are an excellent adjunct to automation, providing the human interaction for the next level of decision-making.

3. Differences in Missions

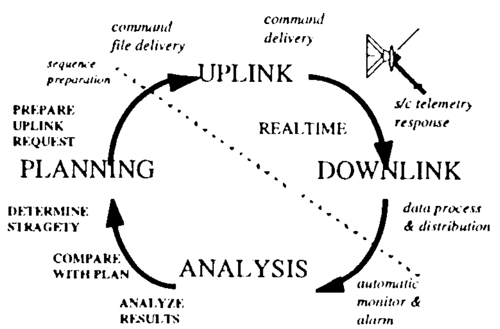
Standardization will certainly help efficiency; and it is needed in Operations; but missions are not all alike. In the past we had simple missions and complex ones. Some were relatively low in cost while others were expensive, flagship class. The flagship class is becoming a thing of the past as funding tightens. We still have a variety of mission classes, as represented by Midex, Discovery, New Millennium, and others. They represent different mission types and different methods to explore space. Operations needs to perform the same basic functions for all of them. We need to watch over them, performing the monitoring function that looks at the end-to-end system to make sure everything is going according to plan. We need to direct them, performing the uplink function that starts with planning and verifies that the required functions have been performed. We need to collect data, which is the downlink process, ensuring that all the data available are safely on the ground and distributed as required, That suite seems relatively standard, and should be standardized to the extent possible. The challenge is to be adaptable to the needs of each of the missions and to balance that adaptability with following standards, using common equipment, and taking advantage of available services. Stardust is a case in point. The original Operations concept was to use multitasking and institutional services. Various factors have changed that concept, giving it a strong multimission flavor, as seen in the teaming of Stardust Operations with the Mars Surveyor Operations Program. The strong commonality of the Stardust and the Mars Surveyor flight systems and the missions' use of the same ground system made this change the obvious choice for efficient operations.

4. Drawing on Past Experience

It is quite natural to use past experience when approaching a new task or challenge. The most obvious reason is that it tells us what works. We also learn what does not work. Sometimes there is resistance to change, but this tends to be rare in Space Operations. Technology advancement. rapidly provides new opportunities. People are eager to try new process innovations and devise new organizations. For a while in deep space exploration, when money was more available, we began to drift into new approaches just for the sake of change—not because an idea was better, but just because it was different. In some cases, this was appropriate, because it brought in new technology that might not otherwise have been affordable. Often it was time and money wasted because someone just wanted to do the job differently. F. fficiency was not a requirement. The danger iay in not carefully taking a systems approach. In Space Operations, you do not get too many second chances. Everything has to work together, finely meshing in a system, to fly the mission successfully. As space funding tightened, new projects looked to find what was available, or what was adaptable, to keep their new launches going. History shows that the Pioneer-class missions, managed out of Ames Research Center, ied in early deep space expiration by being a series of missions that operated under one management structure, and used essentially one Operations group and an evolving ground system, thus making a good contribution to a model of iow cost anti efficiency [i]. These mission innovators started in 1965 with Pioneer 6, went to Venus with probes and orbiter, and are looking at the last of Pioneer 10 as they prepare for the Discovery Lunar Prospector. By contrast, the Clementine mission and the Mars Pathfinder missions tried new management structures and adapted parts of other ground systems for their operations. Both made radical changes to the "proven" operations process to accomplish successful and efficient missions. Stardust, which will be the next of the Discovery class, will realize most of its efficiency by adapting an existing ground and flight system, and simplifying the operations processes. The most common thread in all of these mission classes has been the use of experienced personnel in key roles; these personnel draw on their past experience to know what needs to be done and how best to do it.

5. Operations Processes

The purpose of Operations is to complete the mission, to obtain the results. It is a two-phase process of supplying direction, then getting the effect of the directions. Operations can be defined as two functions, which are split into two parts and form a circle when the "result loop" is included. As shown in the Figure 1, planning and analysis are the two main functions. Their real-time processes are uplink and downlink, respectively. The feedback from analysis can be used to adjust the planning, thus forming the "Operations circle." The process of interaction for conducting a mission has been, and will remain, the same. What will change is how the process is done. In Figure 1, the functions (in lowercase italic type) are related most directly to the real-time activity and will become automated. Some of that automation has already been done, and many more functions have been proposed for automation [2].



OPERATIONS PROCESS

Knowing what has worked in the past, and accepting the new rules for the future, how can we plan for effective operations? The following trends may provide answers:

- Mission plans tend to be more carefully laid out than before, because they are cost driven, which allows more effective estimates of what will be needed during the course of an operation. Some contingency plan is always included; experience guides the assessment of values and risk,

- We are slowly improving the involvement of Operations from the concept stage onward. The Operations focus has generally been on the mission science, the spacecraft, and mission design. Operations, personnel with real-time experience bring valuable lessons into the concept and design phases. They can point out effective methods of design that are operationally efficient and still meet requirements.

- It is most important that Operations take part in the prelaunch testing. It is best, and almost becoming a rule, that the ground system used for testing be the same one that supports operations. This is concurrent engineering. Test it as you will fly it. Concurrent engineering actually starts with the concept, gets refined in the design, does match-mating in the development, and tests the whole package during assembly and prelaunch testing.

  Another factor of efficiency for Operations comes in here: documentation. Certainly it is important to have requirements, plans, procedures and rules well-documented; but it is also important to know where to draw the line. Mars Pathfinder and the Lunar Prospector went almost too far in drawing the line. They went "bare bones" on the documentation, but the necessary agreements and procedures were there.' Some documentation tips:

- Avoid the elaborate documentation tree with many volumes, condense the volumes into sections, and forget all the boilerplate. This saves time and effort and makes for easier consumption of the important parts.

- Putting the documentation online, in a database, is much more efficient than providing multiple printed copies and mail distribution. Also, if you find what you want on a server, it will be the latest version.

These ideas lead to other considerations:

- Resources for operations are limited. Map out operabil ity designs for both the spacecraft and the ground system. It is a mistake to squeeze development money at the cost of driving operations, because the life cycle cost will end up being higher.

- One area often overlooked in the concept and design phase is the amount of Deep Space Network (DSN), or [telecommunication, time that will be needed. Each mission will present unique requirements, but a good general rule is, the more DSN tracking required, the more expensive the operation will. be. This will be especially true when full-cost accounting becomes reality and station time will be charged to the project. Therefore, try to design for flight automation and large on-board storage, and plan to use a "data dump" mode for retrieval.

- Once the plan has passed the development stage, the rest of the operations process should be just a matter of implementing it. This is, of course, a great over-simplification, but if costs are to be kept under control, stick with the plan.

  Implementation then becomes a matter of attending to the details of what was demonstrated during system test. It is known and expected that adjustments will have to be made in the post-launch, or check-out, phase. This is where. Operations' "process" loop is very active, as it involves correcting and adjusting for how the spacecraft actually operates.

- Whereas every part of the operations process was carefully monitored in the past, we know from experience that we can use automation to monitor most functions.

  Therefore., the process of monitoring what is happening throughout the system will depend much more on raising the alarm when a deviation occurs, recording the events, making adjustments, and individual notification or posting of results.

6. Operations Process Trends

The Project Team

The typical project team has already become smaller, and will probably continue to shrink. Multitasking will likely be more prevalent as personnel take on additional duties, aided by process automation.

Multitasking has worked and can work well. It does depend on the talents and personalities of the individuals involved. The term "generalist" has been applied to those who have a penchant for doing and handling multiple tasks on the same project. Here the value and depth of the individuals' knowledge is focused on a single mission. If more in-depth technical knowledge is required, use on-call or consulting services working in the needed specialty, on a case-by-case basis. Buy only what you need. Keep the direct costs for operations to a minimum.

Multimission Teams

Multimission teams have a distinct advantage where there is commonality among missions, These teams tend to be shared over a several missions rather than among all missions, since the commonality extends over the smaller grouping. Multimission teaming allows a greater depth of mission knowledge than can be expected in, for instance, a service environment. Sharing personnel has some limitations when the same operation is going on in parallel. While Murphy's Law says that parallel, high activity, operation will happen, there is at least some limitation imposed by the number of antennas in the DSN and its supporting system, which will help to keep multimission personnel from being overwhelmed. Multimission teams were used in the Pioneer missions and were demonstrated in the cases of Magellan and Voyager real-time operations. The Mars Surveyor Operations Program (MSOP) will be operating all the current and planned Mars missions, because of the missions' common flight system. MSOP will handle a portion of the Stardust mission also, providing flight and spacecraft support at the mission's industry partner, Lockheed Martin in Denver. Stardust is a good example of common usage sharing. It shares a common flight and ground system with the Mars Missions; yet the mission itself is quite different.

Future operations will be more distributed. Large mission-support areas, and all their related costs, are already becoming history. Smaller areas that have special (needs) capabilities are replacing them; these areas are devoted to specific disciplines, such as navigation, image processing, data management and distribution, and the like. Other operations, like command generation, sequence building, scheduling, and subsystem analysis, can be done in a distributed manner within a project server network. Newer, more powerful workstations provide more information more rapidly. Personnel can focus more on the decision-making process.

Operations Services

The Telecommunications and Mission Operations Directorate (TMOD) at the Jet Propulsion Laboratory, which manages the Deep Space Network, is developing a Flight Engineering Services program that will provide a set of standard services or processes to any user of this tracking system. The program will take a catalog approach, allowing a project to pick and choose from a full spectrum of mission operations services. The concept is that a project user would only need to bring in his or her mission objective arrd basic operations plan, and the service would provide full mission life cycle support, extending, that is, from concept through the end of mission. Reality, or old experience, says that it may come to pass. However, it also warns that what may happen instead is that a lot of the program's services will be developed, and be of great benefit to the flight missions, but that the program itself may never reach full maturity. Technology advancements will keep pushing development efforts, constantly bleeding away the limited funding that will be available. Whatever the outcome, there will be distinct gains. The best of these is the downlink data capture and delivery. Strides are already being made in the automation of this service. Using standards, such as the data handling methodology of the Consultative Committee for Space Data Systems (CCSDS), brings missions into arealrnthat is easily accommodated by this service. The monitoring task now performed by project personnel will not be necessary any longer. All the data will be in the right locations for analysis.

Depending on the requirements, the uplink side is usually much more interesting. Theoretically, the more automated a spacecraft is, the less need there is for uplink commanding. Still, the uplink side is the most critical aspect of mission operations. The execution of the mission plan is the focus of the uplink process. This holds true when there is deviation from the plan and correction is needed. Such deviation can be caused by some change in the spacecraft, or it can be caused by a difference between a prediction about the medium being examined and the medium itself. Careful planning and preparation of the uplink file to allow for either contingency are required. These seem, for the foreseeable future, to be in the realm of the mission personnel. Usually joint decisions, i.e., decisions that can include mission science, management (if it entails cost), engineering, and operations, are made. The service system can then provide for the actual upli nk process details, including verification of the results.

Another option, also a service, is referred to by the TMOD organization as the "Beacon" mode. There are applications, such as long cruise to an encounter destination, where this can be very cost-effective. Essentially, it is a check-in type of process in which the cruising spacecraft transmits a continuous signal. The DSN takes a quick peek at the spacecraft periodically, and, based on the modulation tone, can tell what the spacecraft status is and react if necessary. If the spacecraft has an autonomous navigation system, this is very useful. An interim phase of the service is just to have periodic navigation tracks that gather radiometric and angle data while collecting some limited engineering telemetry, thus accomplishing the same status check. This procedure can be relatively cost effective, also. Stardust is using this method for its long cruise. One short navigation track per week is planned, so as to verify the trajectory and plan for maneuvers. Since the mission is six years long, and the spacecraft's comet encounter will take up less than one tenth of that time, the procedure represents a significant benefit to operations efficiency. As so often happens, a benefit is tempered, in this case by the need to collect low-volume cruise science, which means occasional downlinks of stored data from the on-board memory.

Some Suggestions

Be sure to weigh each of these methods carefully before choosing one.

When the Operations team is dedicated, its whole focus is on the a single mission, even when the members are multitasking. With multi mission teams, there is still the sense of focus, at the very least because of mission commonality, but each member's time allotment to any one mission is less than 100 percent. There are other demands on their efforts.

The service approach can be very efficient and effective, but it carries the strengths and limitations of a service. Personnel are directly involved only at the contact points, and they are guided by the requirements and agreements

7. Summary of Effective Operations

This document has tried to make the reader more aware of what works in Flight Operations, what new methods are being developed, and what to look for in the future. The main message is, involve Operations early if you want low cost and efficiency.

There was discussion of the early design trade-offs to be made. While you should use the latest hardware and software, be sure to look at what already exists and works. Consider Commercial Off The Shelf (COTS) software as much as possible. Consider adaptation of existing systems. These practices will reduce development time and cost. Make use of a distributed ground system, especially for science-related interaction. Take advantage of institutional and system-provided services, especially communications services. Try to keep the documentation streamlined, and usc an online documentation system.

The operations process was briefly reviewed, This review is an important factor during the design phase.

Equally important during the design phase are the decisions made about the operations process methods.

The flight service system will be the main force in operations in the new era. A service method can provide the most efficient and cost-effective means to carry out mission operation so as to accomplish the desired purpose of the research.

The push will be toward standards-based systems. Commonality will be equated with low cost for operations. Flexibility will be the key to making mission operations work. Those common systems must be able to accommodate the different types of missions, and the different phases of a given mission.

All these factors come together as a recommendation that you provide a flight-control service that is effective and adaptive, that interacts with new technology, and develops tools and processes of its own, so that you will be successful in the many and varied missions that offer the challenge of the future.

And, finally, if you want low cost with innovation and reasonable risk, mix experience with some of those new ideas. Designing a mission in a vacuum will not be successful. Get the right inputs; and get them early.

8. REFERENCES

[1] National Aeronautics and Space Administration, *Space Pioneers, Where are They Now?*, NASA EP-264, Washington DC: NASA Public Affairs Division,1987.

[2] G. E. Cameron, et al., Cost Efficient Operations for Discovery Class Missions, Coulmbia, Maryland : Applied Physics Laboratory, John Hopkins University, 1994.

9. ACKNOWLEDGMENT

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